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Study of the AGS Random Misalignment Error

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Technical Note

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ABSTRACT

Using the harmonic correction data obtained from the AGS polarized proton operation, we study the possible misalignment error of the AGS magnets. Our results indicate that besides certain systmatic errors, there is certain amount of the random error which seems to match the AGS elevation survey data. Beside the important high energy physics study for the polarized proton, the polarized proton can offer certain amount of information relevant to the improvement of the AGS performance.

1) Introduction

The polarized proton is a useful tool for the study of the machine properties in the AGS. The acceleration of the polarized proton has to pass through many depolarization resonances of the machine in order to reach the high energy. Some of these resonance related to the intrinsic machine structure, while some of these resonances related to the errors in the survey of the machine(imperfection resonances). These imperfection resonances can be used as an indicater for the improvement of the machine errors. In this paper, we shall turn the problem around and ask the question: Can one use these experimental information to derive some message related to the error in the AGS machine?

Table 1. gives the experimental data(ref.1) of the harmonic correctiors used in the polarized proton run. We shall take these numbers to evaluate the closed orbit error and the effective dipole field correction to understand and to compare with the AGS survey data. Finally, we shall use the survey data to calculate the depolarization resonance strength, which shall be compared with the experimental resonance strengths. Section 2 briefly review the the theory(ref.2) of the orbit calculation by assuming these harmonic correctors located uniformly(95 kickers from A-L superperiods). Section 3 gives numerical computations of the effects of these harmonic kickers to the orbit of the beam in the AGS. Using these numerical results, we shall then compare with the AGS survey data. The conclusion is given in Section 4.

TABLE 1. AGS experimental result of harmonic correctors

n		Gauss Clock ON	OFF	a(sin)	b(cos)	sqrt	FWHM(a)	FWHM(b)	1/FWHM *1000
3		2100	2800						
4		3100	3800						
5		4200	4100						
6		5300	6000						
7		6500	7200	5	0	5.00	55.5	59.2	24.70
8		7450	8150	-8	-5	9.43	16.5	14.5	91.81
9		8500	9300	-4	-11	11.70	10	11	135.15
10		9625	10350	-2	-2	2.83	38	38	37.22
11		10750	11350	-10	-2	10.20	46	46	30.74
12		11700	12350	40	-9	41.00	41	73	27.97
13		12700	13450	-10	5	11.18	68	65	21.28
14		13750	14600	5	-13	13.93	73	78	18.76
15		14850	15550	0	-15	15.00	92	79	16.68
16		16000	16700	-5	-10	11.18	85	90	16.18
17		17000	17700	-10	-5	11.18	88	79	17.01
18		18000	18800	5	20	20.62	122	89	13.91
19		19100	19800	10	-10	14.14	83	85	16.84
20		20200	20900	-2	-33	33.06	122	102	12.78
	(20-12)			-8	-10	12.81	120	116	11.99
21		21200	21900	-10	-10	14.14	114	120	12.10
	(21-12)			-12	-19	22.47	36	38	38.26
22		22300	22900	-30	-20	36.06	180	250	6.85
	(22-12)			0	0	0.00	200	200	7.07
23		23100	23900	25	15	29.15	120	99	13.09
24		24100	25000	-5	40	40.31	105	86	15.03
	(36-24)			0	0	0.00	200	200	7.07
25		25150	26000	20	12	23.32	120	109	12.39
	(36-25)			2	0	2.00	116	146	11.01
26		26150	27000	-5	-10	11.18	125	92	13.50
	(36-26)			-10	10	14.14	80	86	17.07
27	(36-27)	27200	28275	-17	-32	36.24	20	23	66.26
28	(36-28)	28400	29200	-25	-25	35.36	38	38	37.22
29		29300	30300	5	-3	5.83	100	100	14.14
	(36-29)			-5	4	6.40	60	96	19.65
30		30400	31300	5	0	5.00	100	100	14.14
31		31400	32400	-5	0	5.00	100	110	13.51
32		32500	33200	20	0	20.00	128	140	10.59
33		33300	34300	0	-30	30.00	174	127	9.75
34		34500	35300	-12	-40	41.76	148	130	10.24
35		35500	36250	20	-60	63.25	120	120	11.79
36		36400	37300	-40	-60	72.11	80	146	14.25
37		37500	38400	-20	-35	40.31	110	104	13.23
38		38550	39400	60	45	75.00	96	110	13.83
39		39550	40350	100	-50	111.80	120	120	11.79
40		40500	41400	30	20	36.06	92	84	16.12
	(60-40)			20	-20	28.28	136	136	10.40
41		41600	42400	-10	5	11.18	86	86	16.44
	(60-41)			0	0	0.00	71	92	17.79

2) The orbit distortion

The closed orbit of the machine in the presence of dipole kickers is given by

$$\frac{d^2y}{ds^2} + K(s)\,y = \frac{\Delta B(s)}{B\rho} \qquad (1)$$

where $\Delta B(s)$ is the field error and $B\rho$ is the magnetic rigidity of the particles. Transforming (1) into normalized phase space using

$$\begin{pmatrix} v \\ v' \end{pmatrix} = \begin{pmatrix} \beta^{-1/2} & 0 \\ \alpha\beta^{-1/2} & \beta^{1/2} \end{pmatrix} \begin{matrix} y \\ y' \end{matrix} \qquad (2)$$

where $v' = dv/d\phi$, with ϕ as betatron phase advance

$$\phi = \int \frac{1}{\beta}\, ds/Q \qquad (3)$$

one obtains

$$\frac{d^2v}{d\phi^2} + Q^2 v = Q^2 \beta^{3/2} \frac{\Delta B}{B\rho} \qquad (4)$$

The closed orbit is the periodic solution of (4) as

$$v(\phi) = \frac{Q}{2\sin\pi Q} \int_{\varphi}^{\varphi+2\pi} f(\psi) \cos Q(\pi+\varphi-\psi)\, d\psi$$

where

$$f(\psi) = \beta^{3/2} \frac{\Delta B}{B\rho} .$$

If the driving component of the orbit is expanded into a Fourier series,

$$f(\varphi) = \sum_k f_k \, e^{ik\varphi}$$

the periodic solution of (4) becomes

$$y = \beta^{-1/2} V = \frac{Q\beta}{2\pi} \sum_n \left[\left(\frac{\Delta B \cdot \Delta l}{B\rho} \right)_a \sin n\phi + \left(\frac{\Delta B \Delta l}{B\rho} \right)_b \cos n\psi \right] \Big/ Q^2 - n^2$$

Thoe closed orbit is most sensitive to the those Fourier components in the field error whose harmonic content is nearest to the tune of the machine Q.

III). Numerical analysis

Using the experimental data obtained from the AGS polarized proton study, we shall analyze the machine properties. Fig.1 shows the absolute kicker strength An/n and Bn/n, where n=G*   =G*c*B /mc^2 with the assumption that the velocity of the particle approaches the speed of light. We note that the harmonic number 12 is the highest contribution in the kicker strength. This may be related to the fact that the AGS machine has certain systematic error. There are many possible causes of the systmatic error in the AGS with superperiodicity of 12. We shall not speculate these systmatic error here.We shall shows that the depolarization resonance strengths observed in the AGS experiment agrees to some extent with that calculated from the AGS survey data in 1985.

Fig.2 shows the consistency of the orbit distortion of 9 and 27 (which uses 9th harmonic to correct the orbit) harmonics compared with the 12th harmonic orbit displacement. We observed that the 9th and the 27th agree with each other and is much larger than the orbit distortion of the 12th harmonic. Similarly, Fig.3 shows the 8th with 28(which uses also 8th) orbit. In the correction scheme, the 8th and the 9th harmonics are intrinsically related the tune of the machine at 8.75. In order to find out the machine error, we shall subtract the orbit error due to the 8 and 9th harmonics and compared with the 12th harmonic. Fig. 4 shows that the orbit error(summation from 7-26 harmonics) excluding the 8 and 9th harmonics in comparison with the 12 th harmonic. We see that the deviation from possible systmatic errors appear at C D and F G H superperiods. Let us now examine the total horizontal field due to these kickers.

Fig.5 shows the field error in the orbit. Again we observed that the superperiods C and F G H are the most important contributor besides the systmatic errors. By making the surmise that the depolarization resonance streength is proportional to the orbit distortion (In reality, the situation is much more complicated), we define the relative resonance strength as

$$\epsilon_n \propto \frac{\sqrt{a_n^2 + b_n^2}}{Q^2 - n^2}$$

Fig. 6 shows the relative depolarization resonance strength from the AGS data of Table 1. Fig. 7 shows the depolarization resonance strength calculated from the 1985 AGS survey data of misalignment error(see Fig. 8)by using the DEPOL program(ref.3).

III). Discussion

We have used the AGS depolarization data to analyze the possible detectable error for the improvement of the AGS machine. The study shows that the harmonic correction do reveal certain consistency of the systmatic and random error in the AGS machine in comparison with the recent AGS survey data. Our analysis proves that the polarized proton does indeed provide useful (beside the important particle physics experiments) information on the transverse vertical plane of the machine properties.

REFERENCES:

1) L. G. Ratner, et. al. , private communications.

2) E.D. Courant and H.S. Snyder, Ann. Phys. 3(1958)1.
   E. Keil, p. 52 CERN-77-13

3) E.D Courant, and R.D. Ruth, Brookhaven Formal report, BNL-51270

Figure Captions:

Fig.1 The normalized resonance strength of the AGS harmonic correctors. Each unit in the vertical scale corresponds to $\Delta B*dL/(B\rho)=.0716$.

Fig.2 Orbit distortion due to the 9th harmonic corrector. The each sacle correspons to 13.9mm of displacement in the vertical direction. Note that the 9th harmonic corrector for the 27th harmonic give identical orbit displacement as that of the 9th harmonic at n=9.

Fig.3 Same as that of Fig.2 but for the 8th and the 28th harmonics, where the 28th harmonic is corrected with 8th harmonic orbit corrector.

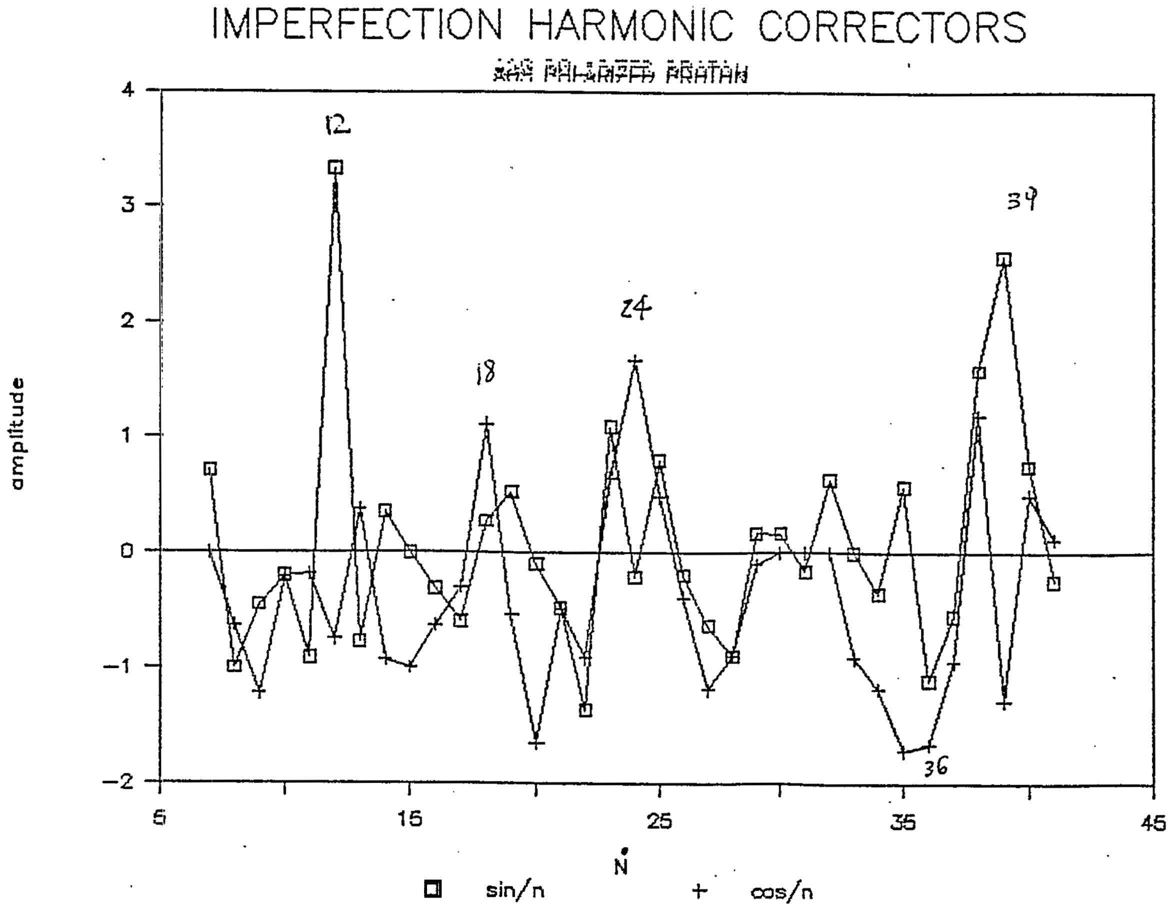
Fig.4 Excluding the intrinsic machine orbit displacements at 8 and 9th harmonics, we compare the total orbit distortion of the possible systmatic contribution of the 12th harmonic with that of all correctors but 8 and 9th. We observed that besides the 12th systmatic error, random error appears most importantly at the C D and F G H superperiods.

Fig.5 Horizontal field error as a ratio the main dipole field as a function of the machine location. Note that the field error does not exclude the 8 and 9th harmonics. Again the field error graph shows some interesting random error appear at C and F G H superperiods.

Fig.6 The imperfection resonance derived from the assumption that the resonance strength is proportional to the amplitude of the orbit distortion.

Fig.7 The imperfection resonance strength calculated from the AGS survey data of vertical misalignment in 1985. This graph should be compared with that of Fig. 6.Note that the imperfection resonances at 21=12+9,27=36-9 and 45=36+9 has dominately the harmonic content of 9. The resonance at 12 is indeed larger than than that calculated with the random number generator for the magnet misalignment. But the calculated strength is however a factor of 3 smaller than that of Fig. 6 (Note the relative strength between 9 and 12 for Figs. 6 and 7). Therefore the discripancy must come from other sources.

Fig.8 The AGS survey data.



~~amplitude~~ Fig. 1

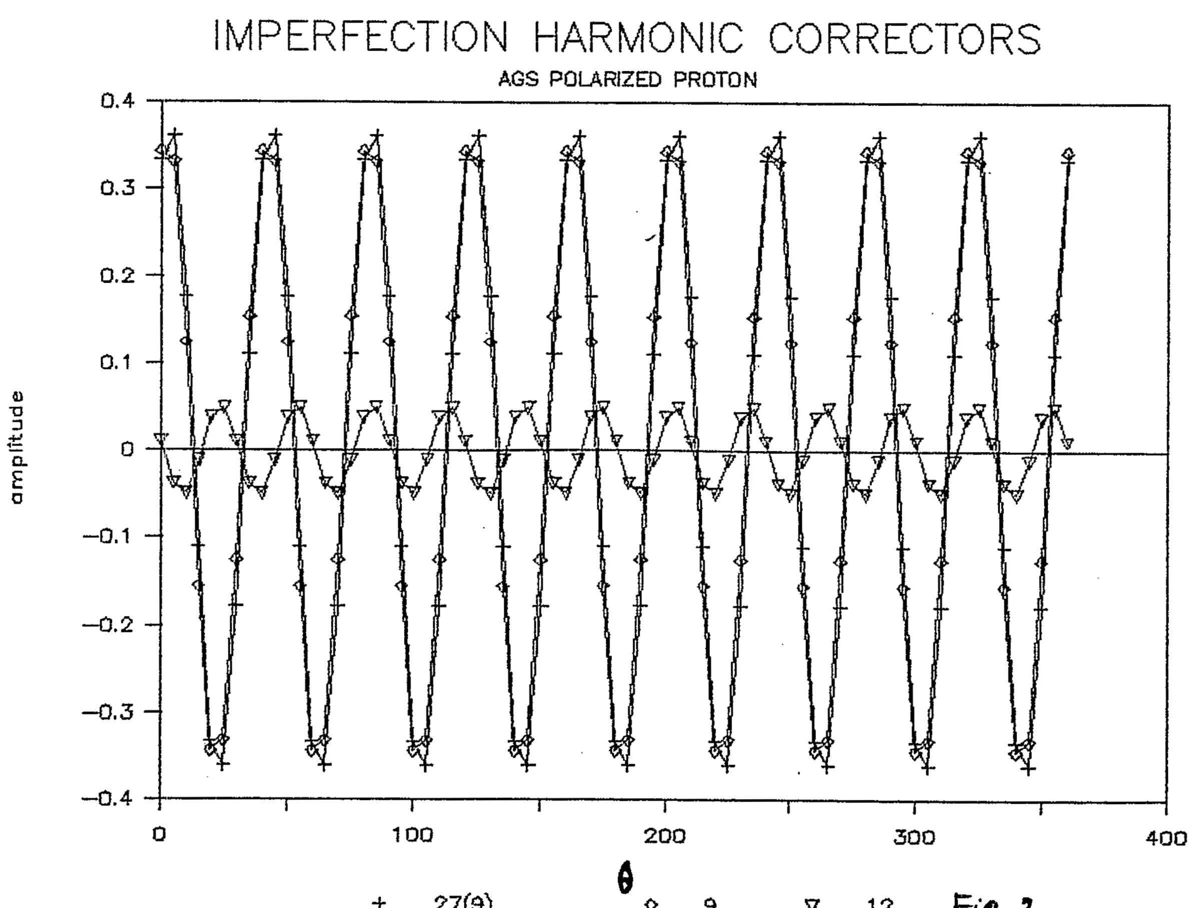


Fig. 2

IMPERFECTION HARMONIC CORRECTORS

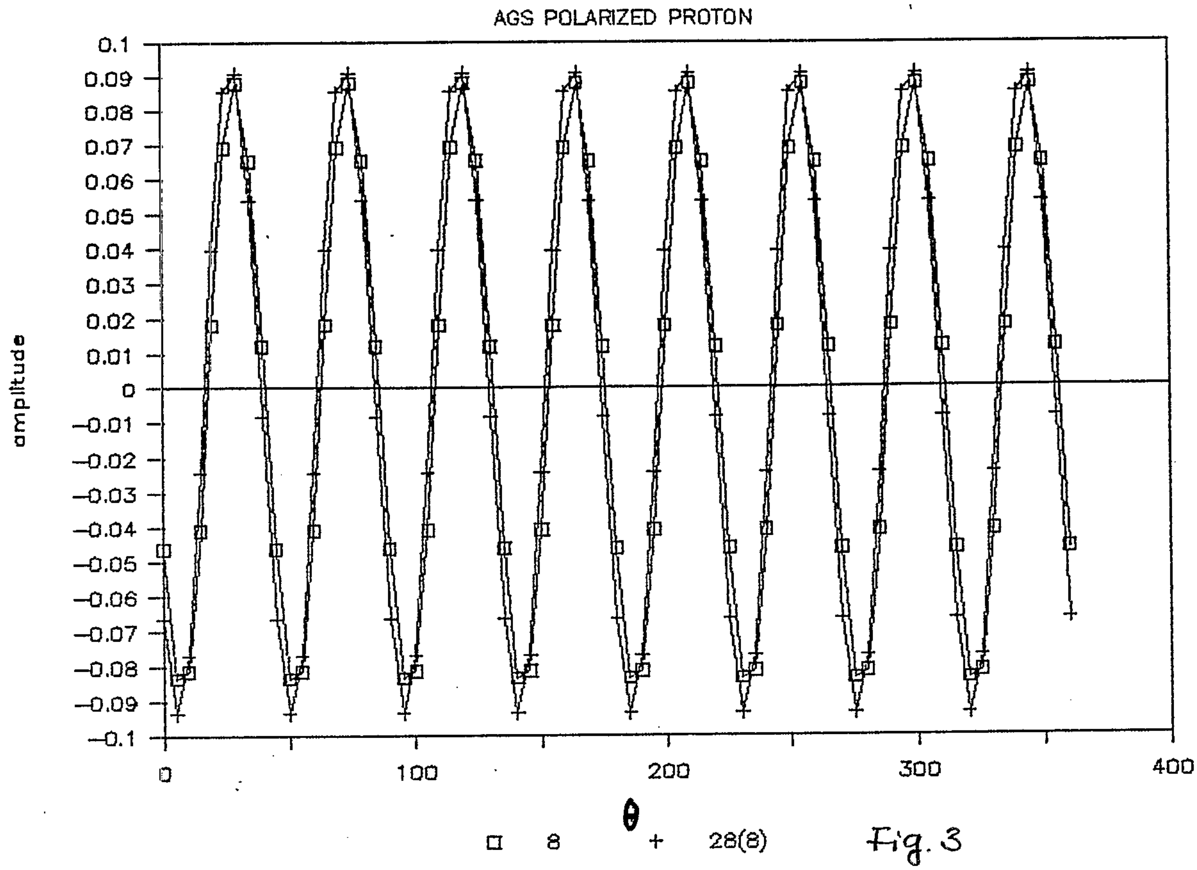


Fig. 3

IMPERFECTION HARMONIC CORRECTORS

SUM= 7 − 26

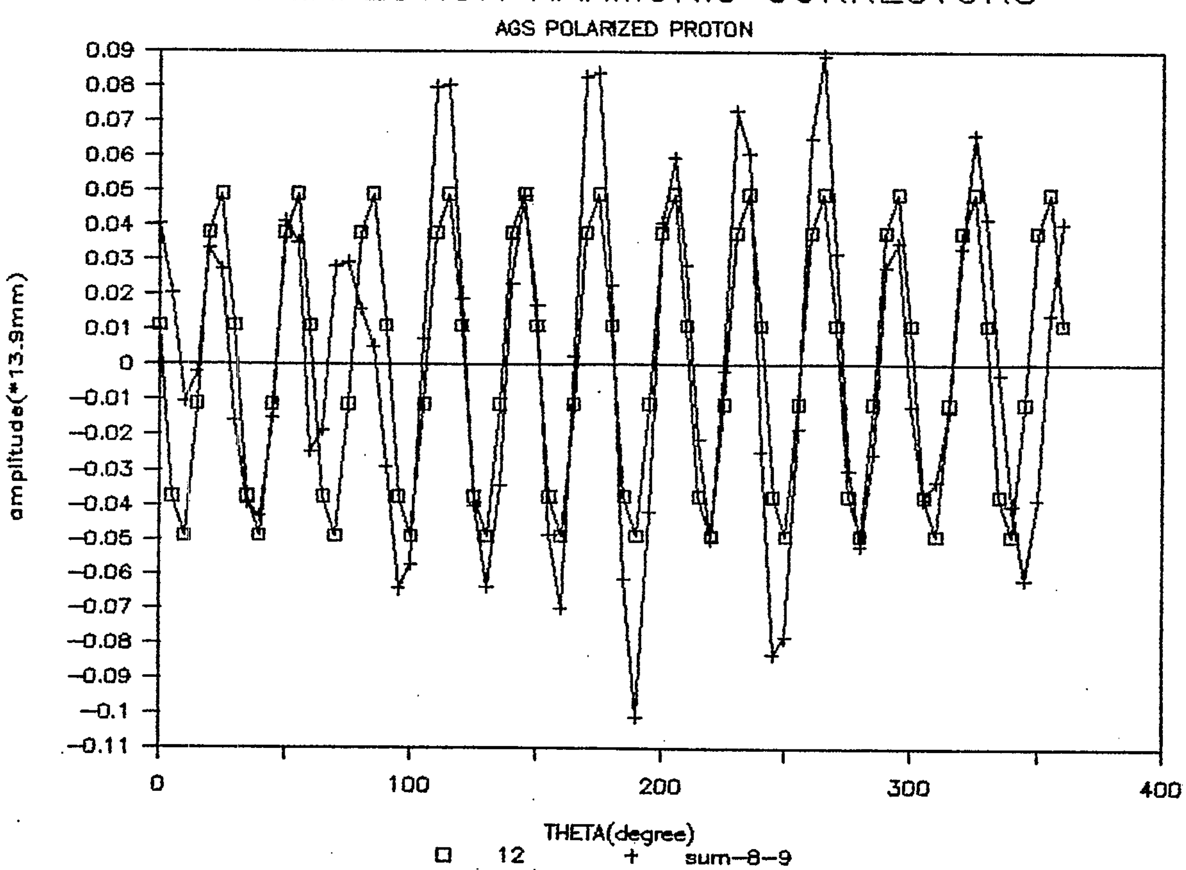


Fig. 4

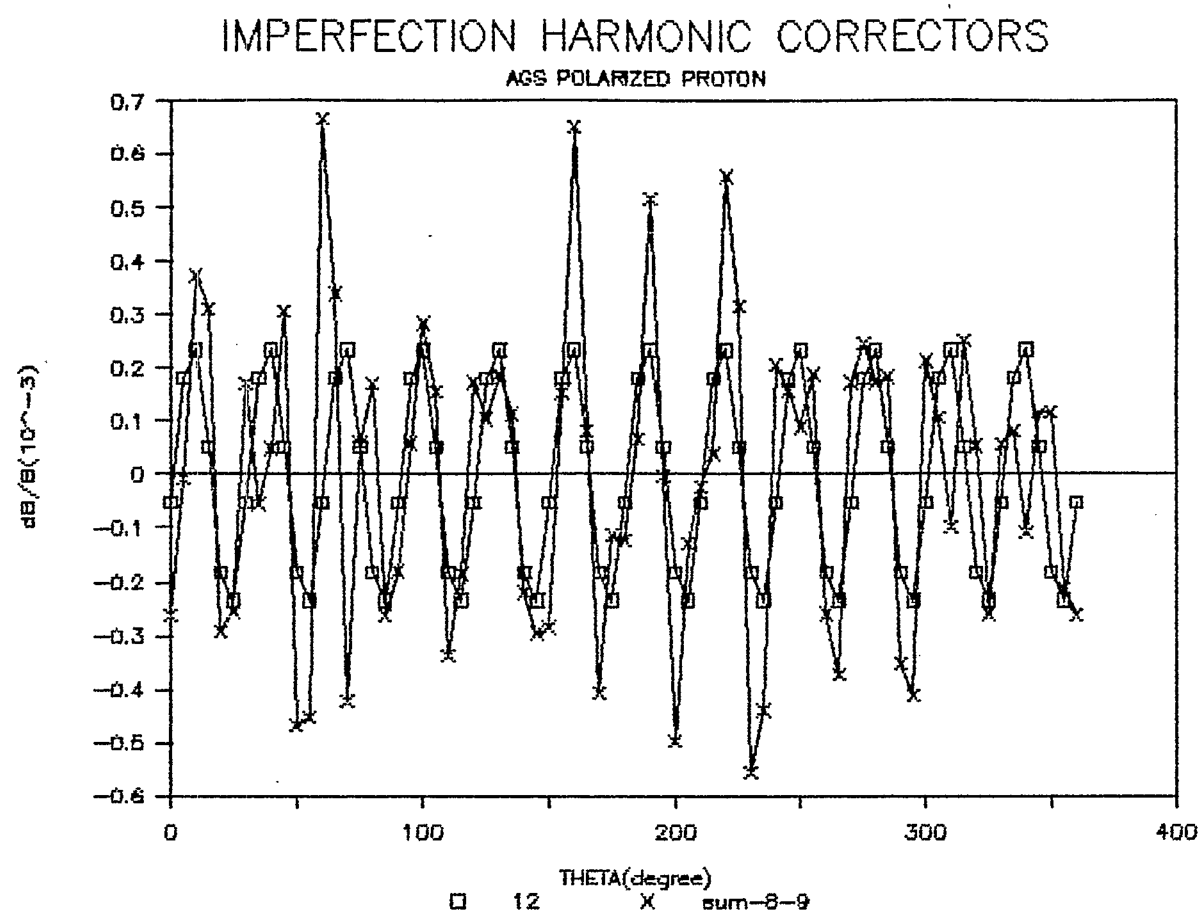

IMPERFECTION HARMONIC CORRECTORS
AGS POLARIZED PROTON
dB/B(10^-3)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
100
200
300
400
THETA(degree)
12
sum-8-9

Fig. 5

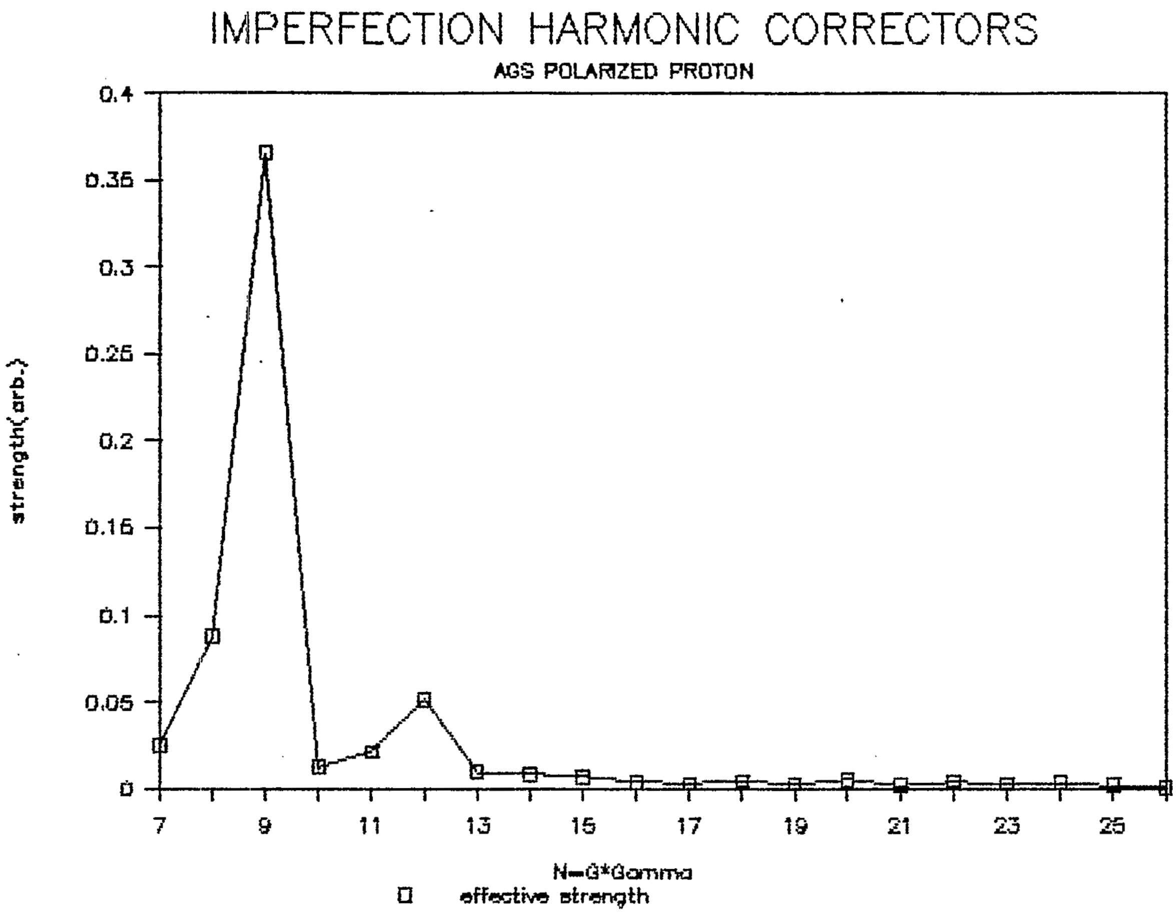

IMPERFECTION HARMONIC CORRECTORS
AGS POLARIZED PROTON
strength(arb.)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
7
9
11
13
15
17
19
21
23
25
N=G*Gamma
effective strength

Fig. 6

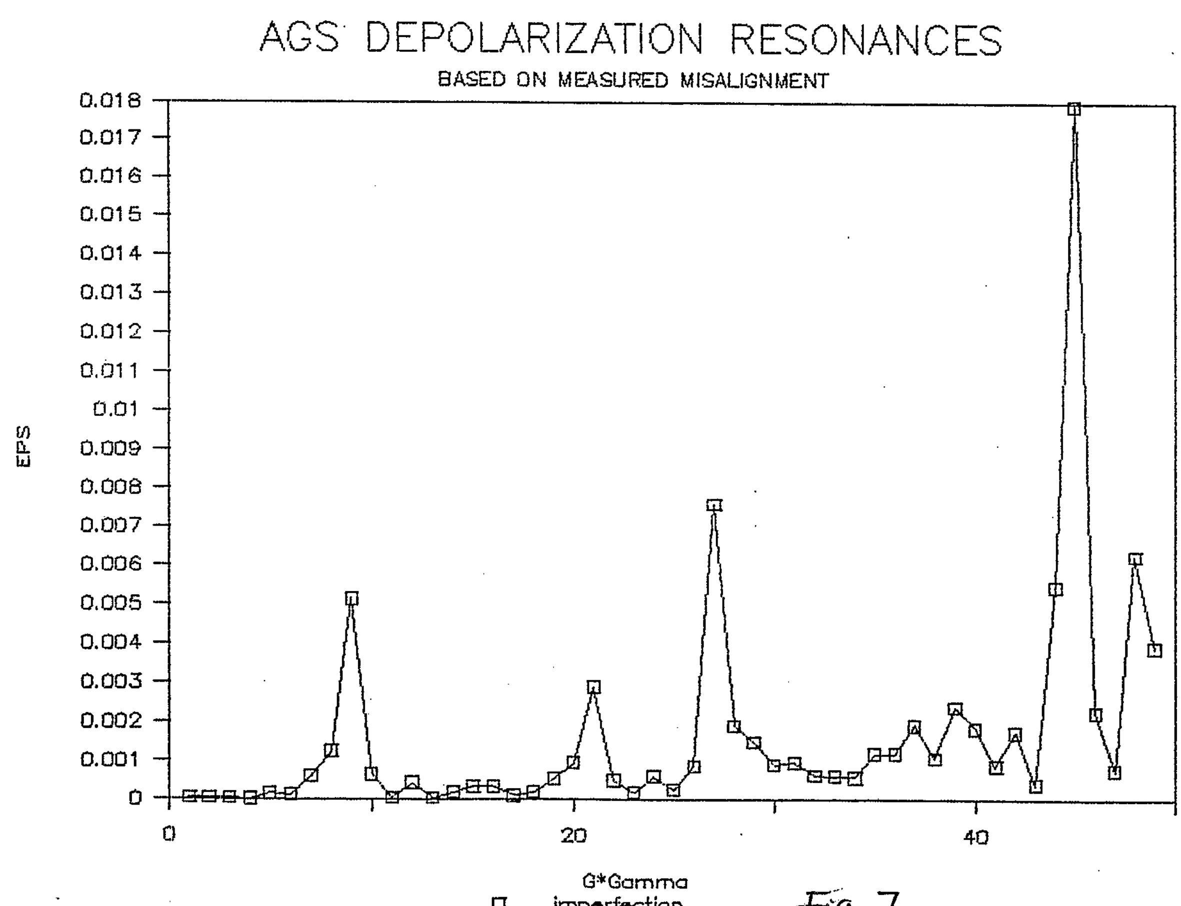
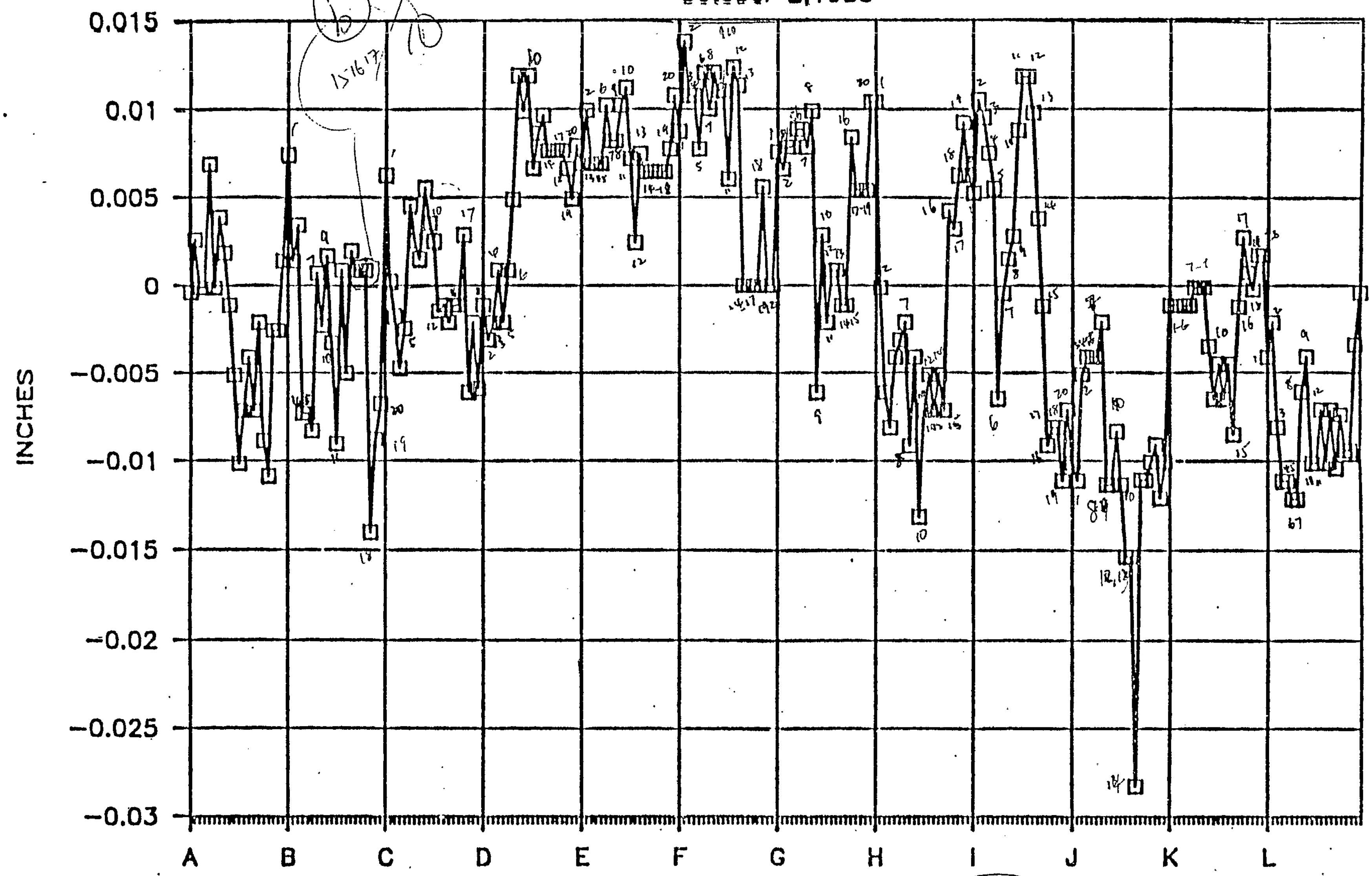

AGS DEPOLARIZATION RESONANCES
BASED ON MEASURED MISALIGNMENT
EPS
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
20
40
G*Gamma
imperfection

Fig. 7

MAGNET ELEVATIONS Figure ~~11~~ 8

October 2,1985



g 10/10